

LOAD DISTRIBUTION AND POSTURAL CHANGES IN YOUNG ADULTS WHEN
WEARING A TRADITIONAL BACKPACK VERSUS THE BACKPACK

A THESIS

SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF SCIENCE

BY

KIMBERLY DEANNA DAHL

D. CLARK DICKIN, PhD. – ADVISOR

BALL STATE UNIVERSITY

MUNCIE, INDIANA

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KIMBERLY DEANNA DAHL

Committee Approval:

Committee Chairperson (Dr. D. Clark Dickin)

Date

Committee Member (Dr. Henry Wang)

Date

Committee Member (Dr. Jennifer Popp)

Date

DEPARTMENTAL APPROVAL:

Departmental Chairperson

Date

GRADUATE OFFICE CHECK:

Dean of Graduate School

Date

BALL STATE UNIVERSITY
MUNCIE, INDIANA
JULY 2015

Declaration

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Kimberly Dahl

Date

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Abstract

THESIS: Load Distribution and Postural Changes in Young Adults When Wearing a Traditional Backpack Versus the BackTpack

STUDENT: Kimberly Dahl

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Over 40 million students in the U.S. use backpacks regularly. Backpacks lead to poor posture due to the posterior placement of the load, which overtime may contribute to low back pain and musculoskeletal complications. This study examined postural and load distribution differences between a traditional backpack (BP) and a nontraditional backpack (BTP) in a young adult population. Using a 3D motion analysis system, 24 healthy young adults (22.5 ± 2.5 years, 12 male) completed both static stance and walking trials on a treadmill with no load and with 15% and 25% of their body weight using the two different backpacks. There was a significant difference in trunk angle, head angle, and lower extremity joint mechanics between the backpack and load conditions during walking ($p < .05$). There was also a significant difference in head angle from pre- to post-walk ($p < .05$). Taken together, the results indicate that the BTP more closely resembled the participants' natural stance and gait patterns as determined by the No Load condition. The more upright posture supported by the BTP may help reduce characteristics of poor posture and ideally help to reduce low back pain while carrying loads.

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Chapter 1

Development of the Problem

Introduction

From the stay-at-home mom to the recreational athlete, military personal, or college student, load carriage can be the most convenient way to transport items from point A to point B. Over 40 million students in the United States use backpacks on a regular basis [1]. This student population uses backpacks to transport school supplies and textbooks between home and school. The practice of carrying heavy loads on one's back has been associated with musculoskeletal pain and injuries. Poor posture brought on by improper backpack use has led to alignment issues such as forward head posture (FHP), rounded shoulders, kyphosis, low back pain, and an asymmetrical axial skeleton. In 2013 alone, over 28,000 backpack-related injuries were treated at medical practices [2].

Posture is the fusion of the position of multiple joints, bones, and muscles along the longitudinal axis of the body [3]. A neutral posture positions all of these components in equilibrium. Ideally, the neutral line of gravity passes through the midline of the mastoid processes, just anterior to the shoulder joints, slightly posterior to the hip joints, anterior to the center of the knee joints, and anterior to the ankle joints [4]. Central to posture is the spine, which carries the weight of the head, chest, and arms and holds the upper body erect [5]. The spine includes three prominent, natural curvatures that act as shock absorbers against compressive forces of daily living [6,7]. Posture also involves the integration of

muscles and joints beginning inferiorly with the ankle followed by the knee, hip, and trunk. Most superior is the atlanto-occipital joint connecting the skull to the spine [4,6,8,9].

Multiple activities contribute to poor posture. In the female population, high heeled shoes shift the center of mass forward. In order to retain balance, the pelvis adopts an anteverted position while the trunk simultaneously extends backward causing hyperlordosis. This puts increased pressure on the spinal curves, specifically the lumbar curve [10]. Work environments which require excessive overhead reaching, arching and twisting, and/or heavy lifting also play a role in the adaptation of poor posture [11,12]. The rise of sedentary jobs which promote prolonged sitting has increased by as much as 80%, and sitting puts more pressure on the lower back than standing by about 40% [13,14]. Postures associated with these activities typically strain the muscles of the back, neck, and shoulders by pulling them forward into a slouched position due to the weight of the head which is no longer over the spine [15]. Load carriage can also lead to poor posture and is of highest concern for the current study. When a load of significant weight is carried on the back studies have shown an increase in forward head position and forward trunk inclination to compensate for the posteriorly displaced center of gravity [16,17].

Continuous poor posture compensations can lead to musculoskeletal imbalances and pain. Forward head posture occurs when the head is held anterior to its neutral, balanced position on top of the cervical vertebrae causing stress on the cervical vertebrae and posterior neck muscles [18,19]. Rounded shoulders develop when the shoulders are anteriorly displaced, causing excessive abduction of the scapulae, due to slouching positions [5]. Low back pain is the third most common reason for doctor visits behind skin disorders and joint disorders. Poor posture contributes to low back pain in 60-80% of the

United States' adult population [20]. Low back pain may be caused by forward flexion of the trunk, which stresses the ligaments and intervertebral discs of the lumbar region [7,14]. Chiropractic care, physical therapy, acupuncture, and yoga may alleviate some of the symptoms brought about by poor posture [21–24].

Load carriage has been around since the beginning of the human species. The first patented backpack was filed in 1882, however, the first backpack aimed at students was not created until the late 1960s [25]. Researchers have investigated the weight of backpacks, the duration of wear, and how they are worn in relation to postural and gait changes. Nearly 85% of adolescents claim back pain was caused by wearing their backpack [26]. Multiple studies have analyzed the appropriate weight for backpacks. Typically, deleterious postural compensations are seen starting at loads of 20% body weight leading to a recommendation of keeping the load of backpacks between 10-15% body weight [27,28]. For static trials, an increase in weight is correlated with an increase in forward head posture, trunk flexion, spinal asymmetry, and tensile forces in the intervertebral discs [29–31].

Backpack loads may also create changes during gait. When wearing a loaded backpack, the duration of the stance phase in gait increases and increases are also seen in the horizontal braking forces [32]. Step length, stride length, cadence and midstance phase increase as well. During gait, ankle and hip range of motion show more dorsiflexion and flexion [33]. Just like with static events, forward head posture and rounded shoulders are more pronounced during gait with increases in backpack load [34,35]. Significant postural changes are seen as additional load further increases forward trunk lean [33].

The nontraditional backpack being used in this study claims to address the postural issues seen in traditional backpacks in its alteration of backpack design and subsequent weight distribution. A similar theory was tested in a double pack design, which placed the load both in front and behind the participant. Compared to regular backpacks, the double pack design showed a decrease in forward trunk lean and a smaller displacement of the wearer's center of mass, which is associated with smaller perturbations during gait [36]. Front packs, where the load is strictly carried in the front of the wearer, have shown less forward head posture than traditional backpacks and less forward flexion at the hip resulting in greater upright posture [37]. However, front packs have also created an increase in thoracic kyphosis [38]. By maintaining a neutral posture through load displacement around the body's vertical axis, the BackTpack seeks to reduce, and perhaps avoid, the deleterious effects of continuous poor posture [39].

Purpose

The principal purpose of this study was to assess postural changes at the spine and assess the effects of load distribution on hip and knee joint mechanics during static stance and walking between a traditional backpack and a nontraditional backpack designed to disperse the load across the body and close to the vertical axis.

Significance

The findings from this study can be used to enhance the current biomechanical literature on backpack wear and the role load distribution plays in the development of a neutral posture. If the design of the nontraditional backpack allows a more neutral posture due to the placement of the load, justification for a shift in the overall design of backpacks may be warranted.

Hypothesis

It was hypothesized that the nontraditional backpack would result in a more upright posture showing less forward trunk inclination and forward head posture. It was also hypothesized that the nontraditional backpack would result in smaller joint moments and powers in the sagittal plane than the traditional backpack.

Limitations

Following the walking trials, participants were asked to turn and face the researcher for the post-walk static collection. This action may have caused the participants to readjust to a straighter stance than if the trial had been collected in the same direction as treadmill walking. Results of this study may not be generalizable to other traditional backpacks since the structure and how it fits may change among brands and even different designs within the same brand. This study also only had participants wearing a backpack for six minutes. The effects of wearing a backpack for shorter or longer durations may or may not return similar results.

Delimitations

Only healthy, young adults with no current musculoskeletal injuries, conditions, or neurological pathologies were included in the study. Participants were between the ages of 18 and 30. Future studies should examine adolescent populations where backpack weight may be heavier than recommended more often than the young adult population. The study was conducted in a laboratory setting. Participants used standardized footwear and completed walking trials on a treadmill, which may have altered normal gait patterns. This study also focused on only two load percentages, whereas a variety of load conditions may exist among students. Although the nontraditional backpack came with a hip belt to

transfer the weight of the load from the shoulders to the hips, participants were instructed not to use it since not all traditional backpacks have that option. Other delimitations included the range and type of weights used for loading the backpacks, how the packs were loaded, and the speed at which participants walked. Other delimitations included the range and type of weights used for loading the backpacks, how the packs were loaded, the speed at which participants walked, and the compound effects of wearing backpacks with no standardized rest period between trials.

Summary

Backpacks are commonly used to carry loads from one place to another. However, recent research has expressed a concern about the load backpacks place on the spine and the proceeding postural compensations. Compensations such as forward trunk inclination, forward head posture, rounded shoulders, and kyphosis may lead to low back pain and postural asymmetries. Few studies have examined nontraditional styles of backpacks and the impact of load distribution and, specifically, distribution relative to the longitudinal axis. Finding a different option for backpack load placement may lead to a more neutral posture during load carriage. Therefore, the purpose of this study was to assess the postural and joint load changes at heel strike caused by differences in weight distribution between a traditional and a nontraditional backpack. The hip and knee joints were selected due to the repercussions of trunk angle that may be seen at these joints.

Chapter 2

Review of Literature

Introduction

Backpacks come in many varieties and serve a large student population as a way to transport textbooks, homework, and supplies between home and school. Different styles of backpacks have been developed over the years, however, the most common style is the traditional two-strap backpack worn over the shoulders with the load placed posteriorly. Multiple studies have examined the effect backpacks have on the development of musculoskeletal pain due to poor posture in relation to the weight of the backpack, the style of backpack, and the duration of wear [26,40–43]. Poor posture brought on by improper backpack use has led to alignment issues such as forward head posture (FHP), rounded shoulders, kyphosis, low back pain, and an asymmetrical axial skeleton. In 2013 alone, over 28,000 backpack-related injuries were treated at medical practices [2].

A recent development in the style of backpacks places the load in line with the vertical axis of the body along its natural line of gravity. No formal research has been done on this style of backpack to test claims of naturally correcting poor posture by keeping the center of gravity in line with the body and thus allowing the wearer to maintain a continuous neutral posture. This study will serve as an exploratory investigation of the postural changes that may occur when wearing a traditional backpack versus a nontraditional backpack. Results of this study could lead to further investigations of the load distribution of backpack styles and further impact the style of backpacks to afford a more neutral posture. Implementing a style of load carriage that enhances correct posture may decrease the musculoskeletal issues brought about by continuous poor posture.

Anatomy of Posture

Posture involves more than just standing with one's shoulders pulled back and looking straight ahead. Rather, at any given moment, posture is the fusion of the position of multiple joints, bones, and muscles along the longitudinal axis of the body [3]. There is no "normal" posture, per say, as normal is different for each body. However, a neutral posture stance has been accepted which places the spine and joints in a neutral position that minimizes the stress placed on them. In this position, the line of gravity is imagined as a plumb line that passes through the body in a way that provides a natural balance. Ideally, this line passes through the midline of the mastoid processes, slightly anterior of the shoulder joints, posterior to the hip joints, anterior to the center of the knee joints, and anterior to the ankle joints [4].

Of particular importance when discussing posture is the spine. The vertebral column holds the upper body erect, and the lumbar section carries a majority of the body's weight [5]. The spine is made up of twenty-four individual vertebrae followed by the fused vertebrae of the sacrum and coccyx. In between the vertebrae are vertebral disks that act as shock absorbers and allow movement to occur [7]. As the spine matures from birth into adulthood, it forms three prominent, natural curves that also serve to divide the spine into sections. From the top, the first section is made up of the seven cervical vertebrae. The twelve thoracic vertebrae form the middle of the back, with the lower back consisting of the five lumbar vertebrae followed by the fused sacral region. This curved nature of the spine allows greater resistance to compressive forces than if the spine were simply a straight rod [6].

The constant adaptation of posture to one's environment requires the integration of multiple joints and muscles. Beginning inferiorly, the line of gravity in neutral posture falls in front of the ankle joints. This pull of gravity forward initiates the contraction of the gastrocnemius and soleus muscles to keep the body from falling forward [4]. The next joint is the knee, where the line of gravity falls anterior to the midline. This puts the knee in extension. In a balanced position, the knee can remain extended without a large amount of muscle activity due to the ligamentous structure of the joint [6]. Superior to the knee joints is the hip and pelvis. Here the line of gravity passes posterior to the hip and through the greater trochanter of the femur. To counteract a posterior pull, the iliopsoas muscle contracts and helps maintain a balanced stance [4]. At the trunk, the line of gravity bisects the curves of the spine anteriorly. Therefore, the posterior muscles of the trunk—the erector spinae—are activated to resist the forward pull [8]. The most superior joint involved with posture is the atlanto-occipital joint, which connects the skull to the spine. The line of gravity passes slightly anterior to this joint, tilting the head forward. This flexion moment is negated by the joint's ligaments, membrane, and joint capsules [9].

Poor Posture Development

High-Heeled Shoes

Many culprits contribute to the development of poor posture. One of these is an accessory that accompanies many women today: high-heeled shoes. Almost fifty-percent of high-heel wearing woman can tolerate heels of at least three inches [44]. However, even the smallest heel will have an effect on posture. Due the nature of high-heeled shoes, the heel of the foot is lifted off the ground by a stiletto while the ball of the foot remains either on the ground or at a level considerably lower than the heel. This arrangement forces the

center of mass of the body to be pushed forward. In order to retain balance, the hips flex forward while the upper half of the body simultaneously extends backward. This puts increased pressure on the spinal curves, specifically the lumbar curve [10].

Job Environment

For some women, high heels may be considered dress code for the work environment. However, there are other factors within a person's work environment that may also contribute to poor posture. Job duties that require a lot of heavy lifting may lead to problems later, especially when proper lifting techniques are not always implemented. Other duties that put strain on the back through excessive arching and twisting are also pragmatic to the maintenance of good posture [12]. For example, firefighters and emergency medical technicians (EMTs) experience postural stress due to the repetitive tasks inherent to the job. Firefighters place strain on the lower back when lifting heavy hoses, while the EMTs endure compromising positions when reaching overhead for supplies and horizontal bending or twisting [11].

Sedentary Behaviors

While some compromising movements may not be relative to all careers sitting is a movement that anyone will find himself or herself in each day, especially with the rise of sedentary jobs. In the 1960s only half of the jobs in the United States did not require moderate intensity physical activity. Now, that number has risen to more than 80% as manual labor jobs such as farming have been replaced with desk jobs [13]. The average person spends about six hours sitting at his or her desk every day during the workweek [45]. This coincides with the 7.7 hours per day people spend in sedentary behaviors, such as sitting, which may include working, watching television, and sleeping [46]. Postures

associated with these activities typically strains the muscles of the back, neck, and shoulders by pulling them forward into a slouched position because the weight of the head is no longer over the spine [15]. While sitting may seem like a time to rest, it actually puts more pressure on the lower back than standing by about 40% [14].

Load Carriage

While many variables can lead to poor posture, of most concern for this study is how load carriage affects posture. From the stay-at-home mom to the recreational athlete, military personnel, or college student, load carriage can be the most convenient way to transport items from point A to point B. The way a load is carried can come in many forms such as sports bags, hiking backpacks, purses, messenger bags, traditional backpacks, and even baby carriers. The problem with these widely accepted forms of load carriage is that they can cause the wearer to engage in poor posture techniques to compensate for the load. When a load of significant weight is carried on the back (such as when using a school backpack, hiking backpack, or baby carrier), studies have shown an increase in forward head position [16]. There is also an increase in forward lean angle at the hip as a compensatory strategy to keep the person standing upright against the posteriorly displaced center of gravity [17].

For loads carried unilaterally, the hazards can be even more detrimental than loads carried bilaterally due to the more extreme postural deviation [29,47]. In order to keep the load from slipping off the shoulder when carried unilaterally, the shoulder girdle becomes elevated on one side. This continues down through the kinetic chain creating frontal spinal curvature (scoliosis) and postural asymmetry. However, unilateral loads carried across the

body on the non-dominant shoulder may be an option to decrease the incidents of these deleterious effects [48].

Risks of Poor Posture Development

Musculoskeletal Risks

Whether from slouching at a computer desk, looking down while reading a book, or having to compensate for heavy loads placed on the back, forward head posture (FHP) is a detrimental effect of continuous poor posture. Forward head posture is a result of the head being held anteriorly to its neutral, balanced position on top of the cervical vertebrae [19]. This places stress on the cervical vertebrae because it removes the natural shock-absorbing curve and instead sends the weight of the head straight to the discs and posterior facets. Forward head posture also places strain on the trapezius and levator scapulae muscles in abnormally bearing the weight of the head [18].

Moving inferiorly, another risk of poor posture development overtime is excessive thoracic kyphosis and rounded shoulders. Rounded shoulders are defined as when the acromion process is anterior to the vertical posture line due to the excessive abduction of the scapulae. Much like FHP, rounded shoulders is caused by activities or positions that anteriorly displace the shoulders [5]. A hyperkyphotic thoracic spine often accompanies rounded shoulders due to the slouched position associated with both. Shortness of breath or labored breathing may result due to the tightening of the pectoral muscles, which restricts the expansion of the rib cage [15]. Another possible outcome of rounded shoulders and excessive thoracic curvature is numbness in the arms as a result of compressed nerves in the shoulder girdle [49].

As the third most common reason for doctor visits (first and second being skin disorders and joint disorders, respectively), low back pain is also a major side effect of poor posture affecting 60-80% of the United States' adult population [20]. Mechanical low back pain is the most common type of axial back pain and is typically caused by "mechanical" problems such as participating in certain activities or maintaining certain positions rather than from genetic spinal disorders [50]. Concerning posture, low back pain may be caused by forward flexion of the lumbar spine resulting in a flattened lumbar curve [14]. This condition is also called swayback or lordosis. When flattened, the lumbar vertebrae close on the anterior aspect and open on the posterior aspect, stretching the ligaments connecting the vertebrae [7].

Treating Poor Posture

With the myriad of deleterious effects brought about by poor posture, there are simple steps that can be taken to either correct or lessen the effect of continuous poor posture. Chiropractic care is one option, especially in finding relief for back pain. Over 20 million Americans visit a chiropractor, and many complain of low back pain [22]. Chiropractors use the adjustment or manipulation of joints to put the body back into alignment, which may help heal maladies without surgery or medication [51]. Another option to help relieve the effects of poor posture is physical therapy. Physical therapists work to reduce pain and restore mobility by training a client to use techniques that promote one's ability to move and perform functional activities correctly [21]. Acupuncture is yet another holistic option to relieve the effects of poor posture. Acupuncture is most commonly used to treat pain and works by inserting extremely thin needles into specific points of the body, which increase blood flow and the activity of the body's natural pain

killers [24]. Yoga is another possible resource to relieve or correct poor posture. Yoga aims to teach proper posture techniques as a way to reduce pain and keep the body in alignment by introducing various poses [23].

Preventing Poor Posture

While the treatments listed above can be helpful in treating the effects of continuous poor posture, the best way to avoid seeking treatment is to maintain correct posture in daily life. Unfortunately, modern culture conspires against incorporating proper posture into daily activities. To combat this reality, the field of ergonomics has developed tips and accessible tools to ward off poor posture. At the office, desks should be situated so that the computer screen is at eye level, keeping the head in line with the spine to prevent the neck from developing FHP and to prevent slouching. Desk chairs should be situated so that the user does not have to strain to reach the desk. Chairs should also provide lumbar support to encourage the natural, slight curve of the lumbar spine and help displace the weight of the torso [52]. There are also alternatives to traditional desks which include treadmill desks and sitting on an exercise ball instead of a traditional chair. For jobs that require prolonged standing or heavy lifting, wearable posture supports are available. Most recognizable is the lumbar support belt which may help relieve lower back pain, although research on the issue is inconclusive [53].

Load Carriage

Backpack History

The human species has been carrying loads on their backs for thousands of years. Although the first patented backpack, called a “pack-strap,” was filed in 1882 by Camille Poirier, the modern day backpack has only been around for about fifty years. Before

backpacks were commonplace in the schoolyard, there was a silent, unnoticeable growth in backpacking for sport. Poirier's pack-strap was created to provide, "a new and improved pack-strap for holding and packing articles of clothing, provisions, and other articles which are to be carried in [a package] on the back" [54]. Dick Kelty designed the first official mountaineering backpack in 1952 [55]. His product immediately became popular and by 1977 backpacking had exploded as a national trend [56].

Meanwhile, university students were looking for ways to carry their school supplies between classes and dorm rooms. The growth in backpacking led to the development of daypacks for recreational hikers. JanSport modified the daypack to suit an academic need, which hit university bookstores in the late 1960s [25]. By 1982, L.L. Bean had joined the backpack community [56]. Since then, the growth, customization, and ergonomics of backpacks has evolved to fit the needs of consumers, and there is no shortage of consumers. In 2013, almost 1.4 million backpack units were sold at a cumulative price of \$2.2 billion – a 104% and 102% increase since 2002, respectively [57].

Backpack Weight

With over 40 million students in the United States using backpacks on a regular basis [1] and back pain as the third most common reason for hospital visits [20], the research in this area has increased in hopes of finding the etiologies of this pain and its possible connection to backpacks. Researchers have investigated the weight of backpacks, the duration of wear, and how they are worn in relation to postural and gait changes [35,58–61].

Much debate has ensued over the appropriate weight people, and especially children, should be toting around in their backpacks. Utilizing questionnaires, studies have

reported almost 75% of adolescent backpack wearers experience back pain [43]. A survey given to children found that 37% identified with experiencing back pain and, of that sample, 82% believed their backpack either caused or worsened the pain [26]. Another study found that backpack load increases with age ranging from 6.2% body weight in kindergarten to 12% body weight by the fifth grade [62]. In contradiction, another study found that backpack weight is proportionately heavier in younger populations. Fifth and sixth graders carried 19% and 21% of their body weight on their backs, respectively, while seventh and eighth graders carried 14% and 15%, respectively [41]. Those numbers offer a bleak outlook on the long-term effects of backpack wear, but how much weight is too much?

A study conducted on university-aged male students explored the difference of 10, 15, and 20% body weight on trunk-lower extremity muscle activity and trunk postural changes. When backpack weight increased, muscular activity in the rectus abdominis significantly increased as well as backward inclination of the trunk [27]. A different study looking at postural changes in relation to backpack load had similar results. With each 5% increase in load, postural changes continued to worsen [28]. The conclusion of both these studies suggested avoiding backpack loads greater than or equal to 20% body weight due to the greatest postural compensations seen at the maximum load. However, even a light load of less than 10% body weight can lead to musculoskeletal pain if worn for long periods of time [40].

Postural Compensations

When significant loads are carried on the back, postural compensations include forward head posture, rounded shoulders, kyphosis, lordosis, scoliosis, and pelvic tilt.

Wearing bags over the shoulder results in an increase in trunk flexion, and unilateral load carriage creates asymmetry along the spine [29]. A study on military personnel investigated the effects of increasingly heavy loads. As load size increased, the torso became more and more horizontal, indicating trunk flexion, and the anterior aspect of intervertebral discs was compressed while the posterior region was stretched. The kinematics of the spine were speculated to change in accordance with keeping the center of mass in natural alignment [31].

Under neutral conditions, the erect body posture matches the natural line of gravity. However, when a load is placed on the back such as when wearing a backpack, the auditory meatus shows forward displacement along the sagittal plane anterior to the line of gravity [63]. This is connected to forward head posture, which is measured at the craniovertebral angle [28]. Misalignment of the natural s-curve shape of the spine also reduces its ability to act as a shock absorber. This may lead to back pain and muscle overuse as it tries to maintain balance [64]. When wearing a load for a period time, curvature of the spine increases with fatigue, increasing tensile forces in the intervertebral discs [30].

Gait Compensations

While postural compensations can be seen extensively during static measurements, load carriage also affects gait. When wearing a loaded backpack, the duration of the stance phase in gait increases and increases are also seen in the horizontal braking forces. A reduction in the vertical ground reaction force peak is also seen, which may be explained by the longer stance phase allowing the force to be dispersed over a longer period of time [32]. Forward head posture and rounded shoulders during gait is also affected by increased backpack loads, specifically from no weight to 10 and 15% of body weight [65]. Trunk

inclination is more affected by loads of 20% body weight compared to lighter loads [35].

One study, however, found the opposite. For male university students wearing loads of 10, 15, and 20% body weight, significant changes in trunk backward lean were seen [58].

A study done on military personnel showed that when a load was added multiple changes in gait kinematics occurred. Step length, stride length, cadence and midstance phase all increased. Ankle and hip range of motion also significantly increased, showing more dorsiflexion and flexion. A significant postural change was seen as the load addition created more forward trunk lean [33]. Further studies on soldiers confirmed this, along with evidence of increased forward head position and increased range of motion at the knees and hip [34].

Measurement of Compensations

Postural compensations have been measured by analyzing reflective marker placement from 2-D photographs [28]. Markers were placed on the left side of the body on the tragus of the ear, shoulder, hips, thigh, knee and ankle as well as on the spinous process of C7. Another study utilized reflective markers to measure adaptation in trunk inclination, side flexion, and rotation. These markers were placed on the shoulders, elbows, wrists, sacrum, thigh, knee, and foot and were analyzed using motion analysis [27,58].

Spinal analysis has been measured using a spring-loaded backpack [30], an Integrated Shape Imaging System 2 [29], and MRIs [31]. The current study will utilize the sonoSens Monitor. The sonoSens monitor measures spinal positioning using ultrasound signals, and has been tested for validity and reliability in trunk forward inclination, and lumbar sagittal posture [66–68].

Nontraditional Backpacks

The BackTpack (BackTpack LLC, Salem, OR, USA) claims to address the postural issues seen in traditional backpacks in its alteration of the backpack design and subsequent weight distribution. Support for this idea may be seen with the similar double pack design, which places the load in both the front and the back. Compared to regular backpacks, double packs show a decrease in forward trunk lean and a smaller displacement of the wearer's center of mass. Smaller trunk flexion is associated with smaller perturbations during gait [36]. With the BackTpack, weight is placed in large pockets on either side of the wearer's hips. According to the manufacturer, this keeps the weight distribution along the body's natural line of gravity in the vertical axis. By having the weight placed here, the BackTpack claims to support a neutral posture because the spine and torso do not have to compensate for the posterior load by leaning forward. Therefore, the wearer can remain upright throughout the duration of wear and keep his or her head on top of the shoulders in proper alignment. While not exactly like the BackTpack, front packs have shown less forward head posture than traditional backpacks and less forward flexion at the hip. Altering the load placement resulted in greater upright posture at the neck and hip [37], however, front packs have also induced an increase in thoracic kyphosis [38]. By maintaining a neutral posture, the BackTpack seeks to reduce, and perhaps avoid, the deleterious effects of continuous poor posture [39].

Purpose

The purpose of this study is to assess the postural and gait differences between wearing a traditional backpack and wearing a backpack designed to disperse weight close to the body along its vertical axis. Increasing the likelihood of maintaining neutral posture

may decrease the amount of suffering caused by poor posture (e.g. FHP, rounded shoulders, kyphosis, lower back pain). If the design of the nontraditional backpack allows a more neutral posture, justification for a shift in the overall design of load distribution in backpacks may be warranted.

Chapter 3

Methodology

Participants & Sampling Procedures

Power analysis indicated a sample size of twenty healthy young adults (ages 18-30), who were recruited from the local college campus through word of mouth and written communication in the form of emails.. Participants were free from lower extremity and back injury and any other musculoskeletal or neurological condition that would inhibit their ability to carry a backpack at 15% and 25% of their body weight. Participants had a history of carrying a traditional backpack on a regular basis (3+ days/week). This sample population of college students was ideal due to the high volume of backpack wearers who travel long distances across campus and are without locker storage.

Measurements

This study used a 14-camera Vicon infrared motion capture system (VICON Inc., Denver, CO, USA) collecting at 120 Hz and an AMTI force plate instrumented treadmill (AMTI Inc., Watertown, MA, USA) collecting at 2400 Hz. A traditional backpack and the BackTpack (BackTpack LLC, Salem, OR, USA) were used for load carriage. Load was added to the backpacks using weights in increments of one, five, and ten pounds to equal 15% and 25% of the wearer's body weight. This load was evenly distributed in the backpacks, placing the heaviest weight closest to the spine for the traditional backpack and balancing the weights between the two pockets for the BackTpack.

Experimental Procedures

Following IRB approval, each participant came in one time to the biomechanics laboratory. Participants signed a university approved informed consent form and completed a health demographic questionnaire, which also asked approximately how many days per week (avg. $5.4 \pm .83$) and for how many years (4+) they used a backpack. Participants were then fitted with compression clothing to assist with marker placement and data collection. Participants were also fitted with standardized footwear to minimize discrepancies among personal footwear.

Anthropometric measurements of hand thickness, wrist width, elbow width, shoulder off set, ankle width, knee width, leg length, and inter-ASIS distance were recorded as well as height and weight in accordance with a modified full Plug-In Gait model. From the weight measurement, 15% and 25% of the participant's body weight was calculated to determine appropriate backpack loads. Lastly, each participant was outfitted with reflective markers of a modified full Plug-In Gait marker set, which included clusters for the thigh and shank as well as an additional marker for the iliac crest.

Calibration recordings were taken for the motion capture system. The participant was then properly fitted with the loaded traditional backpack and BackTpack. Proper fitting for the traditional backpack involved both of the shoulder straps at even lengths with the bottom of the backpack falling just above the wearer's hips [69]. Proper fitting for the BackTpack had each compartment level with the elbow with both shoulder straps at an even length. Each participant completed ten tasks: static recordings with no backpack and each of the two backpacks, in addition to both backpacks at the two load percentages, as well as walking trials with and without each of the backpacks at each load percentage. The order in which the backpacks were worn was randomized across participants. For static

trials, participants stood still for approximately 5 seconds while data was collected. For walking trials, participants walked at a constant speed of 1.4m/s (3.2mph) for six minutes. Data was collected at one, three, and five minutes for 7 seconds each.

Design and Analysis

This study was exploratory in nature. The variables studied included head position and trunk angle in the sagittal plane. Moments and joint angles at the hip and knee in the sagittal and frontal planes were also assessed. Motion capture marker trajectories were captured and reconstructed using Vicon Nexus (Version 1.8.5 VICON Inc., Denver, CO, USA). The filtered quantitative output of the spinal position and joint mechanics were collected from Visual 3D software (Version 5.0, C-Motion, Germantown, MD, USA). Head angle was calculated relative to the trunk and trunk angle was calculated relative to the global coordinate system. Data was then analyzed using two one-way RM ANOVAs to compare the load percentages back to the No Load condition. A two-way RM ANOVA was used to compare the backpack and load percentages to each other. These tests were run for both the walking and the static trials. Follow-up pairwise contrasts were performed to determine the location of significant differences. Where sphericity was violated, Greenhouse-Geisser correction was utilized. All analyses were conducted using SPSS (Version 19 for Windows, SPSS Inc., Chicago, IL, USA). The alpha level was set at $p < .05$. Bonferroni correction was run to reduce the chance of a Type I error.

Chapter 4

Results

Walking

Backpack and Load

Kinetics

When comparing the two types of backpacks to each other and to the two load conditions, significant differences were discovered for the main effect of backpack and load on vertical GRF ($F_{1,23}=6.31$, $p=.02$; $F_{1,23}=283.11$, $p<.001$), where the BTP had a higher impact peak than the BP and the 25% load had a larger impact peak than the 15% load. Backpack and load had a significant main effect on sagittal knee moment ($F_{1,23}=18.37$, $p<.001$; $F_{1,23}=79.95$, $p<.001$) where BTP and 15% load had a lower sagittal knee moment than the BP and 25% load, respectively. Frontal knee moment had a significant interaction between backpack and load ($F_{1,23}=15.57$, $p=.001$). Frontal knee moment increased more dramatically between the two loads for the BP than for the BTP. There was a significant main effect of backpack type, but not load, on sagittal ($F_{1,23}=13.00$, $p=.001$) and frontal ($F_{1,23}=6.65$, $p=.02$) hip moment. The BTP had higher moments at the hip in the frontal and sagittal plane than the BP.

Kinematics

There was a significant main effect of backpack on head angle ($F_{1,23}=44.48$, $p<.001$), trunk angle ($F_{1,23}=164.01$, $p<.001$), impact knee angle ($F_{1,23}=7.726$, $p=.01$), and peak hip angle ($F_{1,23}=10.66$, $p=.003$) in the sagittal plane. Ignoring load, the BTP had a significantly more upright head angle than the BP. Load percentage had a significant main effect on head

angle ($F_{1,23}=10.67$, $p=.003$), trunk angle ($F_{1,23}=123.35$, $p<.001$), impact knee angle ($F_{1,23}=6.98$, $p=.02$) and peak hip angle ($F_{1,23}=42.20$, $p<.001$). The 15% load had more upright head angle than the 25% load. There was a significant interaction between backpack and load on trunk angle ($F_{1,23}=15.48$, $p=.001$), impact knee angle ($F_{1,23}=7.35$, $p=.01$), and peak hip angle ($F_{1,23}=12.38$, $p=.002$). The BP had a more dramatic increase in trunk flexion than the BTP as load increased. At impact, the knee angle for the BTP only became marginally more flexed, while the BP showed a much more substantial difference in knee angle as load increased. A similar pattern was seen for maximum hip angle as load increased. Group means for the kinetic and kinematic data during walking can be seen in Table 1.

No Load vs. 15% Load

Kinetics

Load had a significant main effect on vertical GRF ($F_{2,46}=143.69$, $p<.001$), sagittal knee moment ($F_{2,46}=14.22$, $p<.001$), frontal knee moment ($F_{2,46}=21.39$, $p<.001$), and frontal hip moment ($F_{1.05, 24.03}=7.63$, $p=.01$). Follow-up pairwise comparisons (Table 2) revealed that at 15%, the BTP and BP had a significantly higher impact peak ($p<.001$), sagittal knee moment (BTP: $p=.03$, BP: $p<.001$), and frontal knee moment ($p<.001$) than the No Load condition, but were not significantly different from each other. For frontal hip moment, post-hoc analysis revealed the BTP had a larger moment than both the No Load ($p=.02$) and BP ($p=.04$) conditions.

Kinematics

Load had a significant main effect on head angle for all three pack conditions ($F_{1.56, 35.86}=58.83$, $p<.001$). Pairwise contrasts (Table 2) revealed the BTP and BP had a larger

head angle than the No Load condition ($p < .001$), and the BTP had smaller head angle than the BP condition ($p = .001$). Load also had a significant main effect on trunk angle between all three pack conditions ($F_{1,60, 36.79} = 164.96$, $p < .001$), with pairwise comparisons revealing forward trunk flexion increasing from No Load to BTP to BP. There was a significant main effect found for load on peak hip angle ($F_{2,46} = 18.89$, $p < .001$). Follow-up pairwise comparisons revealed the BTP and BP had significantly larger peak hip angles than the No Load condition ($p = .001$, $p < .001$) but were not significantly different from each other.

No Load vs. 25% Load

Kinetics

For the 25% load, there was a main effect on all of the variables examined: vertical GRF ($F_{2,46} = 295.12$, $p < .001$), loading rate ($F_{2,46} = 4.25$, $p = .02$), sagittal knee moment ($F_{2,46} = 54.14$, $p < .001$), frontal knee moment ($F_{2,46} = 35.75$, $p < .001$), sagittal hip moment ($F_{2,46} = 5.48$, $p = .01$), and frontal hip moment ($F_{2,46} = 90.73$, $p < .001$). Follow-up pairwise comparisons (Table 2) revealed sagittal knee moments were significantly larger for both backpacks compared to the No Load condition ($p < .001$) and for the BP compared to the BTP ($p = .001$). There were also significant differences for both backpacks from the No Load condition for impact peak ($p < .001$), and frontal knee moment ($p < .001$), but no significant differences between the two packs. The BTP had significantly larger sagittal ($p = .04$) and frontal ($p = .04$) hip moments than the No Load condition. Unexpectedly, the BP had a significantly lower loading rate than the No Load condition ($p = .02$).

Kinematics

There was a main effect of the 25% load on head and trunk angle between all three pack conditions ($F_{2,46} = 78.79$, $p < .001$; $F_{2,46} = 263.28$, $p < .001$), where head angle became

significantly more hyperextended from the No Load to the BTP and then BP condition while forward trunk flexion significantly increased from No Load to BTP to BP. A significant main effect was also found for impact knee angle ($F_{2,46}=12.55$, $p<.001$) and peak hip angle ($F_{2,46}=35.15$, $p<.001$). Post-hoc analyses revealed the BP had a significantly more flexed knee angle at impact than both the No Load ($p=.002$) and BTP ($p<.001$) conditions. Peak hip angle was significantly larger for both backpacks compared to the No Load condition ($p<.001$), and for the BP compared to the BTP ($p=.003$).

Static

Backpack and Load

There was a significant main effect of time ($F_{1,23}=6.60$, $p=.02$), backpack ($F_{1,23}=53.10$, $p<.001$), and load ($F_{1,23}=33.28$, $p<.001$) on head angle. Head angle became significantly more hyperextended between pre- and post-walk, when wearing the BP compared to the BTP and as load increased from 15% to 25% (Table 3). There was a significant interaction between time and backpack ($F_{1,23}=5.32$, $p=.03$) and between backpack and load ($F_{1,23}=8.36$, $p=.008$) on trunk angle. Collapsed across load, trunk angle had a sharper increase for the BP than the BTP between pre- and post-walk. Going from 15% to 25% with the BP had a larger increase for trunk angle than the BTP when collapsed across time.

No Load vs. 15%

Time had a significant main effect on head angle ($F_{1,23}=10.42$, $p=.004$). From pre- to post-walk, head angle became significantly more hyperextended. There was significant main effect of load on head angle ($F_{2,46}=66.08$, $p<.001$) and trunk angle ($F_{2,46}=199.10$, $p<.001$). Pairwise comparisons revealed that head angle was significantly more

hyperextended between both backpacks and the No Load condition ($p<.001$). The BP head angle was also significantly more hyperextended than the BTP ($p=.002$) at 15% load. For trunk angle, post-hoc analysis revealed significantly more forward trunk flexion with a 15% load between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$).

No Load vs. 25%

Time had a significant main effect on head angle ($F_{1,23}=7.06$, $p=.01$). Head angle became significantly more hyperextended from pre- to post-walk. There was significant main effect of load on head angle ($F_{1,59,36.51}=130.84$, $p<.001$) and trunk angle ($F_{2,46}=169.19$, $p<.001$). Pairwise comparisons revealed that head angle was significantly more hyperextended between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$) at 25% load. For trunk angle, post-hoc analysis revealed a 25% load produced significantly more forward trunk flexion between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$).

Chapter 5

Discussion

The primary goal of the current study was to analyze both gait and posture in response to changes in load distribution between two different types of backpacks in a young adult population during heel strike. It was hypothesized that the BTP would result in more upright posture than the BP, which was confirmed for both walking and static trials with less forward trunk lean and head tilt for the BTP over the BP. It was also hypothesized that joint moments at the hip and knee in the sagittal plane would be less for the BTP. This hypothesis was only true for the knee at the 25% load.

Posture

During walking, postural changes were seen between the two backpacks. At both load percentages, there was more forward trunk lean for the BP than the BTP. This is likely the result of the load being placed behind the wearer with the BP and more axially with the BTP. In order to maintain upright balance, the person must compensate for the posterior pull of the load by leaning forward [23,24] enabling them to keep their overall center of gravity within the base of support. The BTP, however, places the load in line with the vertical axis, which allows the wearer to maintain a more upright torso position. A more erect stance allows the spine to maintain its natural curvature and thus may reduce the likelihood of low back pain caused by the flattening of the lumbar spine when the trunk is flexed [9]. Head angle is likely a reflection of trunk angle in that as the trunk bends forward, the head must be hyperextended in order for the person to look straight ahead and not at the ground. Consequently, given that the BP resulted in more forward trunk lean, the head

position was more hyperextended than the BTP. Hyperextension is involved in forward head posture, which may result in shoulder and neck pain [12]. It also places undue stress on the cervical vertebrae because it removes the natural shock-absorbing curve and instead sends the weight of the head straight to the discs and posterior facets [7].

The significantly more flexed knee angle at impact for the BP at 25% may relate to the larger forward trunk lean. Flexion at the knee would allow for more absorption of the heavier load not only in the backpack, but also due to more mass being placed over the knee joint caused by trunk flexion. This may actually be a positive adjustment since, at 25%, the BP had a smaller loading rate and thus may reduce the stress at the joint. Peak hip angle may also tie back into forward trunk lean since a more flexed trunk will create a smaller angle between the thigh and the trunk even if the leg itself is not being lifted higher. Therefore, the significant differences reported for peak hip angle may simply be a reflection of the greater forward trunk lean seen with the BP at the 25% load.

While differences were seen between backpacks during walking, changes were still seen when standing immediately after walking with the backpack on. Just as with walking, posture at the head and trunk angle were significantly worse for the BP than the BTP. Only head angle was affected by time, which may be because at the end of walking the person may have been able to readjust his or her trunk angle to reflect a more upright stance. However, both head and trunk angle continued to be affected by load. Other studies also reported worsening posture with an increase in load [11,12,25]. The pre- and post-walk differences in head and trunk angle may indicate a residual effect of walking with a backpack.

Gait

Many of the significant differences seen regarding the kinetic variables were expected. For example, for both backpacks at both load percentages, it was expected that vertical ground reaction force impact peaks would be higher than the No Load condition. What was unexpected was the higher loading rate for the No Load condition than the BP loaded at 25%. This may be related to the more flexed knee angle at impact for the BP talked about previously. The straighter leg in the No Load condition would create more of a rigid lever, which may cause the load to be accepted more rapidly and reduce the absorption capabilities [26]. The larger sagittal knee moment of the BP compared to the BTP at 25% may be related to the more flexed trunk angle. Leaning forward at the trunk may place more mass over the knee joint. To maintain stability, the knee may then have to produce larger extensor moments. Frontal knee moments swapped, where the BTP was larger during the 15% load, but the BP was larger for the 25% load. Excessive frontal knee moments may increase risk for knee osteoarthritis [71]. So when approaching a load where these two trends meet, it may be beneficial to switch from the BP to the BTP. The BTP had a larger frontal hip moment than the BP at the 15% load, which may be due to the location of the weight for the BTP versus the BP. The location of the pockets of the BTP may produce more side-to-side movement during walking whereas the BP would produce, or potentially augment, the more typical front-to-back movement seen in gait.

While this study provided significant results, there are things to consider for future studies that may enhance the quality of the results. This study only examined two load conditions. More meaningful results may surface through the investigation of multiple load percentages where a pattern might be seen in how rapidly posture and gait are affected. It may also be advantageous to use weights which replicate the size and shape of objects

typically placed in backpacks (e.g. textbooks, laptop computers, notebooks). This may allow the space of the backpack to be filled more properly instead of being loaded with weights that may have slid around and affected how the backpack was carried.

No standard rest period was built into this study. Therefore, results may show a compound effect of wearing a backpack due to the quick exchange between packs and weights. Future studies should examine differences between these backpack types while including a rest period as well as among different populations such as children, older adults, and special populations. Multiple backpack brands could be analyzed as well as the use of a hip support belt found on some backpacks, which is meant to load the weight at the hips instead of the shoulders. Investigations may also consider analyzing muscular activity, the spatio-temporal parameters of gait at standardized and self-selected speeds, and the differences between these backpacks during activities of daily living such as riding a bike and stair navigation.

Conclusion

Even though the data suggest the BTP may support better posture, it may be difficult for people to make the switch to a new type of backpack simply because the traditional backpack is what people know. The traditional backpack also allows the arms to swing freely. Having pockets on the side, like with the BTP, may limit a person's natural arm movement. Ideally, people would not use backpacks at all because even at the 15% load, deviations in posture and gait occurred; however, the cessation of backpack use is not realistic.

In conclusion, although the nontraditional design is not widely accepted as the standard for backpacks, it may be more advantageous to adopt it into mainstream

backpack use. While not exactly equal to the No Load condition, the load displacement of the BTP did allow the wearer to maintain a more upright posture than the BP—the trunk was more erect and the head assumed a less hyperextended position. The more upright posture assumed by the BTP may reduce the deleterious effects of poor posture such as neck and shoulder pain, low back pain, and musculoskeletal asymmetries. While not always significantly different from the BP, the BTP more closely resembled the participants' natural gait patterns as determined by the No Load condition.

Chapter 6

Manuscript

The following research article was written with the intention of being submitted to the *Gait and Posture* journal for publication after completion of the project.

Load Distribution and Postural Changes in Young Adults When Wearing a Traditional Backpack Versus the BackTpack

KIMBERLY D. DAHL^a, HE WANG^a, JENNIFER POPP^b, D. CLARK DICKIN^a

^aBiomechanics Laboratory, Ball State University

2000 W. University Ave

Muncie, IN 47306

^bSchool of Physical Education, Sport, and Exercise Science, Ball State University

2000 W. University Ave

Muncie, IN 47306

Address for correspondence:

D. Clark Dickin, PhD.

Biomechanics Laboratory

Room HP 311

Ball State University

Muncie, IN 47306

Phone: (Int+1) 765-285-5178

Fax: (Int +1) 765-285-8762

Email: dcDickin@bsu.edu

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Abstract

Over 40 million students in the U.S. use backpacks regularly. Backpacks lead to poor posture due to the posterior placement of the load, which overtime may contribute to low back pain and musculoskeletal complications. This study examined postural and load distribution differences between a traditional backpack (BP) and a nontraditional backpack (BTP) in a young adult population. Using a 3D motion analysis system, 24 healthy young adults (22.5 ± 2.5 years, 12 male) completed both static stance and walking trials on a treadmill with no load and with 15% and 25% of their body weight using the two different backpacks. There was a significant difference in trunk angle, head angle, and lower extremity joint mechanics between the backpack and load conditions during walking ($p < .05$). There was also a significant difference in head angle from pre- to post-walk ($p < .05$). Taken together, the results indicate that the BTP more closely resembled the participants' natural stance and gait patterns as determined by the No Load condition. The more upright posture supported by the BTP may help reduce characteristics of poor posture and, ideally, help to reduce low back pain while carrying loads.

Keywords: load carriage, trunk posture, gait, head angle

Highlights

- Examines backpack load distribution effects on posture and gait.
- Traditional backpack results in more forward trunk flexion and neck hyperextension.
- Nontraditional backpack more similar to unloaded posture than traditional backpack.

1. Introduction

Load carriage can be the most convenient way to transport items from point A to point B across many areas of life (e.g. military, students, athletes). Over 40 million students in the United States use backpacks on a regular basis [1]. Improper backpack use has led to alignment issues such as forward head posture (FHP), rounded shoulders, kyphosis, low back pain, and an asymmetrical axial skeleton [2–4]. In 2013 alone, over 28,000 backpack-related injuries were treated at medical practices [5].

Posture is the fusion of the position of multiple joints, bones, and muscles along the longitudinal axis of the body [6]. A neutral posture positions these components in equilibrium. However, continuous poor posture compensations can lead to musculoskeletal imbalances and pain. Forward head posture occurs when the head is held anterior to its neutral, balanced position and causes stress on the cervical vertebrae and posterior neck muscles [7,8]. Low back pain may be caused by forward flexion of the trunk, which stresses the ligaments and intervertebral discs of the lumbar region [9,10].

Researchers have investigated the weight of backpacks, duration of wear, and postural and gait changes during load carriage. Typically, deleterious postural compensations are seen starting at loads of 20% body weight [11,12]. For static trials, increased weight is correlated with an increase in forward head posture, trunk flexion, spinal asymmetry, and tensile forces in the intervertebral discs [4,13,14]. Backpack loads can also impact gait by increasing horizontal braking forces [15], dorsiflexion at the ankle, and flexion at the hip and knee [16]. Changes similar to static posture during backpack use

are seen during gait including forward head posture, rounded shoulders, and forward trunk lean [16–18].

Alterations in backpack load distribution have been assessed using a double-pack design, which distributed the load both in front and behind the participant and demonstrated decreased forward trunk lean and smaller center of mass displacement compared to traditional backpacks [19]. Alternatively, front packs, which place the load anterior to the wearer, produce less forward head posture than traditional backpacks and less forward hip flexion resulting in greater upright posture [20]. However, front packs have also created an increase in thoracic kyphosis [21]. By maintaining a neutral posture through load displacement around the body's vertical axis, nontraditional backpacks seek to reduce, and perhaps avoid, the deleterious effects of continuous poor posture [22].

The principal purpose of this study was to assess postural changes at the spine and assess the effects of load distribution on hip and knee joint mechanics during static stance and heel strike during walking between a traditional backpack and a nontraditional backpack (load placed bilaterally on the wearer). It was hypothesized that the nontraditional backpack would result in more upright posture showing less forward trunk inclination and forward head posture. It was also hypothesized that the nontraditional backpack would result in smaller joint moments in the sagittal plane than the traditional backpack.

2. Methods

2.1 Participants & Sampling Procedures

Twenty-four healthy young adults (22.5 ± 2.5 years, 12 male) participated in this study. Participants were free from lower extremity and back injury and any other

musculoskeletal or neurological condition inhibiting their ability to carry a backpack at 15% and 25% of their body weight. Participants had a history of carrying a traditional backpack on a regular basis (3+ days/week) and completed a university approved consent form and health questionnaire prior to participation.

2.2 Measurements

Posture and gait mechanics were captured using a 14-camera Vicon infrared motion capture system (VICON Inc., Denver, CO, USA) and an AMTI force instrumented treadmill (AMTI Inc., Watertown, MA, USA) collecting at 120 and 2400 Hz, respectively. A traditional backpack and a BackTpack (BackTpack LLC, Salem, OR, USA) were used to manipulate load carriage. Load was added to the backpacks using weights in increments of one, five, and ten pounds to equal 15% and 25% of the wearer's body weight. This load was evenly distributed in the backpacks, placing the heaviest weight closest to the spine for the traditional backpack and balancing the weights between the two pockets for the BackTpack.

2.3 Procedures

Anthropometric measurements, height, and weight were recorded and a modified Plug-In Gait marker set was used that included standard retro-reflective markers and four-marker shank and thigh clusters on each leg. Weight measurements were used to determine appropriate backpack loads of 15% and 25% body weight.

Participants completed ten tasks: static recordings before and after walking with no backpack and each of the two backpacks, in addition to both backpacks at the two load percentages, as well as walking trials with and without each of the backpacks at each load percentage. Backpack and percent load were randomly chosen, however, the No Load

condition always came first. Participants walked at a constant speed of 1.4m/s for six minutes to help desensitize them to the backpack.

2.4 Design and Analysis

Variables studied included sagittal plane head position and trunk angle as well as sagittal and frontal plane hip and knee moments and joint angles. Motion capture marker trajectories were captured and reconstructed using Vicon Nexus (Version 1.8.5 VICON Inc., Denver, CO, USA). Filtered quantitative output of spinal position and joint mechanics were calculated using Visual 3D software (Version 5.0, C-Motion, Germantown, MD, USA). Head angle was calculated relative to the trunk, and trunk angle was calculated relative to the global coordinate system. Data was then analyzed using separate one-way RM ANOVAs to compare load percentages to the No Load condition. A two-way RM ANOVA was used to compare backpack and load percentages to each other. Tests were run for both the walking and static trials. Follow-up pairwise contrasts were performed to determine the location of significant differences. Where sphericity was violated, Greenhouse-Geisser correction was utilized. All analyses were conducted using SPSS (Version 19 for Windows, SPSS Inc., Chicago, IL, USA). Bonferroni corrections were used to reduce Type I error and alpha level was set at $p < .05$.

3. Results

3.1 Walking - Backpack vs. Load Kinetics and Kinematics

Contrasting the two types of backpacks to each other and the two load conditions resulted in significant differences for both backpack and load on vertical GRF ($F_{1,23}=6.31$, $p=.02$; $F_{1,23}=283.11$, $p<.001$), where the BTP had a higher impact peak than the BP and the 25% load had a larger impact peak than the 15% load. Backpack and load had a significant

main effect on sagittal knee moment ($F_{1,23}=18.37$, $p<.001$; $F_{1,23}=79.95$, $p<.001$) where BTP and 15% load had a lower sagittal knee moment than the BP and 25% load, respectively. Frontal knee moment had a significant interaction between backpack and load ($F_{1,23}=15.57$, $p=.001$). Frontal knee moment increased more dramatically between the two loads for the BP than for the BTP. There was a significant main effect of backpack type, but not load, on sagittal ($F_{1,23}=13.00$, $p=.001$) and frontal ($F_{1,23}=6.65$, $p=.02$) hip moment. The BTP had higher frontal and sagittal plane hip moments than the BP.

There was a significant main effect of backpack on head angle ($F_{1,23}=44.48$, $p<.001$), trunk angle ($F_{1,23}=164.01$, $p<.001$), impact knee angle ($F_{1,23}=7.726$, $p=.01$), and peak hip angle ($F_{1,23}=10.66$, $p=.003$) in the sagittal plane. When collapsing across load, the BTP elicited significantly more upright head angle than the BP. Load percentage had a significant main effect on head angle ($F_{1,23}=10.67$, $p=.003$), trunk angle ($F_{1,23}=123.35$, $p<.001$), impact knee angle ($F_{1,23}=6.98$, $p=.02$) and peak hip angle ($F_{1,23}=42.20$, $p<.001$). The 15% load had more upright head angle than the 25% load. There was a significant interaction between backpack and load on trunk angle ($F_{1,23}=15.48$, $p=.001$), impact knee angle ($F_{1,23}=7.35$, $p=.01$), and peak hip angle ($F_{1,23}=12.38$, $p=.002$). The BP had a more dramatic increase in trunk flexion than the BTP as load increased. At impact, knee angle for the BTP underwent only marginal amounts of flexion, while the BP produced a much larger difference in knee angle as load increased. A similar pattern was seen for maximum hip angle as load increased (Table 1). ***Insert Table 1 about here***

3.2 Walking - No Load vs. 15% Load Kinetics and Kinematics

Load had a significant main effect on vertical GRF ($F_{2,46}=143.69$, $p<.001$), sagittal knee moment ($F_{2,46}=14.22$, $p<.001$), frontal knee moment ($F_{2,46}=21.39$, $p<.001$), and frontal

hip moment ($F_{1.05, 24.03}=7.63$, $p=.01$). Load also had a significant main effect on head angle ($F_{1.56, 35.86}=58.83$, $p<.001$) and trunk angle ($F_{1.60, 36.79}=164.96$, $p<.001$) between all three pack conditions. There was a significant main effect found for load on peak hip angle ($F_{2,46}=18.89$, $p<.001$). Follow-up pairwise comparisons can be seen in Table 2. ***Insert Table 2 about here***

3.3 Walking - No Load vs. 25% Load Kinetics and Kinematics

For the 25% load, there was a main effect on all of the kinetic variables examined: vertical GRF ($F_{2,46}=295.12$, $p<.001$), loading rate ($F_{2,46}=4.25$, $p=.02$), sagittal knee moment ($F_{2,46}=54.14$, $p<.001$), frontal knee moment ($F_{2,46}=35.75$, $p<.001$), sagittal hip moment ($F_{2,46}=5.48$, $p=.01$), and frontal hip moment ($F_{2,46}=90.73$, $p<.001$). As well as a main effect on head and trunk angle between all three pack conditions ($F_{2,46}=78.79$, $p<.001$; $F_{2,46}=263.28$, $p<.001$), a significant main effect was also found for impact knee angle ($F_{2,46}=12.55$, $p<.001$) and peak hip angle ($F_{2,46}=35.15$, $p<.001$). Post-hoc analysis for all significant main effects can be seen in Table 2.

3.4 Static - Backpack and Load

There was a significant main effect of time ($F_{1,23}=6.60$, $p=.02$), backpack ($F_{1,23}=53.10$, $p<.001$), and load ($F_{1,23}=33.28$, $p<.001$) on head angle. Head angle became significantly more hyperextended between pre- and post-walk, when wearing the BP compared to the BTP and as load increased from 15% to 25% (Table 3). There was a significant interaction between time and backpack ($F_{1,23}=5.32$, $p=.03$) and between backpack and load ($F_{1,23}=8.36$, $p=.008$) on trunk angle. Collapsed across load, trunk angle had a sharper increase for the BP than the BTP between pre- and post-walk. Going from

15% to 25% with the BP had a larger increase for trunk angle than the BTP when collapsed across time.

3.5 Static - No Load vs. 15%

Time had a significant main effect on head angle ($F_{1,23}=10.42$, $p=.004$). From pre- to post-walk, head angle became significantly more hyperextended. There was significant main effect of load on head angle ($F_{2,46}=66.08$, $p<.001$) and trunk angle ($F_{2,46}=199.10$, $p<.001$). Pairwise comparisons revealed a significantly hyperextended head angle between both backpacks and the No Load condition ($p<.001$). The BP head angle was also significantly more hyperextended than the BTP ($p=.002$) at 15% load. For trunk angle, post-hoc analysis revealed significantly more forward trunk flexion with a 15% load between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$).

3.6 Static - No Load vs. 25%

Time had a significant main effect on head angle ($F_{1,23}=7.06$, $p=.01$), which became significantly more hyperextended from pre- to post-walk. There was significant main effect of load on head angle ($F_{1.59,36.51}=130.84$, $p<.001$) and trunk angle ($F_{2,46}=169.19$, $p<.001$). Pairwise comparisons revealed that head angle was significantly more hyperextended between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$) at 25% load. For trunk angle, post-hoc analyses revealed that the 25% load produced significantly more forward trunk flexion between both backpacks and the No Load condition ($p<.001$) and between the BP and BTP ($p<.001$).

4. Discussion

The primary goal of the current study was to determine the impact of load distribution between two backpack styles in young adults on both gait and posture. The hypothesis that the BTP would result in more upright posture than the BP was confirmed for both walking and static trials with less forward trunk lean and head tilt for the BTP over the BP. It was also hypothesized that joint moments at the hip and knee in the sagittal plane would be less for the BTP, which was confirmed but only for the knee at the 25% load.

4.1 Posture

During walking, postural changes were seen between the two backpacks. At both load percentages, there was more forward trunk lean for the BP than the BTP. This is likely the result of the load being placed behind the wearer with the BP and more axially with the BTP. In order to maintain upright balance, the person must compensate for the posterior pull of the load by leaning forward [23,24] enabling them to keep their overall center of gravity within the base of support. The BTP, however, places the load in line with the vertical axis, allowing the wearer to maintain a more upright torso position. A more erect stance allows the spine to maintain its natural curvature and thus may help reduce the likelihood of low back pain caused by the flattening of the lumbar spine with trunk flexion [9]. Head angle is likely a reflection of trunk angle in that as the trunk bends forward, the head must be hyperextended to allow the person to look straight ahead and not at the ground. Consequently, given that the BP resulted in more forward trunk lean, the head position was more hyperextended than the BTP. Hyperextension is involved in forward head posture, which may result in shoulder and neck pain [12]. It also places undue stress

on the cervical vertebrae because it removes the natural shock-absorbing curve and sends the weight of the head straight to the discs and posterior facets [7].

The significantly more flexed knee angle at impact for the BP at 25% may relate to the larger forward trunk lean. Flexion at the knee would allow for more absorption of the heavier load not only in the backpack, but also due to more mass being placed over the knee joint caused by trunk flexion. Therefore, knee flexion may help lessen the loading rate and thus may reduce the stress at the joint. Peak hip angle may also relate to forward trunk lean since a more flexed trunk will create a smaller angle between the thigh and the trunk even if the leg itself is not being lifted higher. Therefore, the significant differences reported for peak hip angle may simply be a reflection of the greater forward trunk lean seen with the BP at the 25% load.

While differences were seen between backpacks during walking, changes were still present when standing immediately after walking with the backpack on. Just as with walking, posture at the head and trunk angle were significantly more hyperextended and flexed, respectively, for the BP than the BTP. Only head angle was affected by time, which may be because at the end of walking the person may have been able to readjust his or her trunk angle to reflect a more upright stance. However, both head and trunk angle continued to be affected by load. Other studies also reported worsening posture with an increase in load [11,12,25]. The pre- and post-walk differences in head and trunk angle may indicate a residual effect of walking with a backpack.

4.2 Gait

The ability to carry loads while walking in this study demonstrated an expected increase in GRF regardless of the type of pack used. Coupled with this, larger sagittal knee

moments of the BP compared to the BTP at 25% were revealed that may be related to the more flexed trunk angle. Leaning forward at the trunk places more mass over the knee joint requiring the knee to produce larger extensor moments. Interestingly, frontal plane knee moments were larger at 15% load for the BTP than the BP but switched at the 25% load. Given that the risk of developing knee osteoarthritis may increase with excessive frontal knee moments [27], further research is needed to more clearly define the effect of load on knee loading, especially in the frontal plane. At the 15% load there was also a larger frontal hip moment with the BTP than the BP, which may be a result of the location of the weight for the two packs. The lateral location of the pockets of the BTP may produce more side-to-side movement during walking whereas the BP would produce, or potentially augment, the more typical front-to-back movement seen in gait. An unexpected finding was the higher loading rate for the No Load condition than the BP loaded at 25%. This may be related to the more flexed knee angle at impact for the BP mentioned previously. The straighter leg in the No Load condition would create more of a rigid lever, which may cause the load to be accepted more rapidly and reduce the absorption capabilities [26].

While it was determined that there were differences in gait and posture as a function of the type of pack used, and ultimately the location of the load relative to the axial skeleton, there were some study limitations. Although the order of backpack style and load was randomized and participants were able to rest between pack exchanges, there was no standard rest period in this study. Therefore, the compound effect of wearing a backpack may be a function of limited rest during the exchange between packs and weights. Future studies should examine differences between these backpack types among different populations such as children, older adults, and special populations. Investigations may also

consider analyzing muscular activity of both the trunk and lower extremities, the spatio-temporal parameters of gait, and the differences between these backpacks during activities of daily living such as walking at a self-selected pace and stair navigation.

5. Conclusion

In conclusion, while not equal to the No Load condition, the load displacement of the BTP did allow the wearer to maintain a more upright posture than the BP—the trunk was more erect and the head assumed a less hyperextended position. The more upright posture assumed by the BTP may reduce the deleterious effects of poor posture such as neck and shoulder pain, low back pain, and musculoskeletal asymmetries. While not always significantly different from the BP, the BTP more closely resembled the participants' natural gait patterns as determined by the No Load condition.

Conflict of Interest: There was no conflict of interest regarding this study among any of the authors.

Table 1. Mean (SD) of kinetic and kinematic variables during walking trials.*Kinetic Variables*

	No Load	BTP 15%	BTP 25%	BP 15%	BP 25%
Impact Peak (VGRF)^{a,b}	1.20 (.09)	1.37 (.08)	1.49 (.08)	1.35 (.08)	1.47 (.08)
Loading Rate	2.64 (.63)	2.58 (.54)	2.57 (.55)	2.55 (.66)	2.45 (.60)
Sag Knee Moment^{a,b}	1.01 (.24)	1.12 (.29)	1.29 (.29)	1.20 (.30)	1.44 (.35)
Frontal Knee Moment^b	0.67 (.16)	0.77 (.20)	0.79 (.22)	0.74 (.20)	0.82 (.20)
Sag Hip Moment^a	1.04 (.21)	1.38 (.88)	1.57 (.94)	1.02 (.53)	1.12 (.65)
Frontal Hip Moment^a	1.18 (.23)	1.92 (1.20)	1.71 (.94)	1.26 (.25)	1.52 (.65)

Kinematic Variables

	No Load	BTP 15%	BTP 25%	BP 15%	BP 25%
Head Angle^{a,b}	-19.12 (10.38)	-12.66 (9.58)	-11.46 (9.79)	-9.02 (9.24)	-6.09 (9.96)
Trunk Angle^{a,b}	1.75 (3.87)	-2.77 (4.29)	-5.12 (3.68)	-7.94 (4.48)	-12.14 (4.80)
Impact Knee Angle^{a,b}	0.50 (3.46)	1.15 (3.46)	1.31 (3.77)	0.99 (3.65)	3.44 (4.35)
Peak Hip Angle^{a,b}	36.54 (4.88)	38.58 (4.95)	39.48 (5.01)	39.81 (5.44)	42.74 (5.92)

Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

a: $p < .05$ collapsed across backpacks

b: $p < .05$ collapsed across load

Table 2. Post-Hoc Comparisons for 15% and 25% Significant Main Effects.

Kinetics	Load	Post-Hoc Differences	Post-Hoc Significance	Kinematics	Load	Post-Hoc Differences	Post-Hoc Significance
Impact Peak (VGRF)	15 & 25%	BTP ↑ NL BP ↑ NL	p < .001 p < .001	Head Angle	15%	NL ↑ BTP NL ↑ BP BTP ↑ BP	p < .001 p < .001 p = .001
Loading Rate	25%	NL ↑ BP	p = .016		25%	NL ↑ BTP NL ↑ BP BTP ↑ BP	p < .001 p < .001 p < .001
Sag Knee Moment	15%	BTP ↑ NL BP ↑ NL	p = .027 p < .001				
	25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p = .001	Trunk Angle	15 & 25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p < .001
Frontal Knee Moment	15 & 25%	BTP ↑ NL BP ↑ NL	p < .001 p < .001	Impact Knee Angle	25%	BP ↑ NL BP ↑ BTP	p = .001 p = .001
Sag Hip Moment	25%	BTP ↑ NL	p = .036	Peak Hip Angle	15%	BTP ↑ NL BP ↑ NL	p = .001 p < .001
Frontal Hip Moment	15%	BTP ↑ NL BTP ↑ BP	p = .024 p = .044		25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p = .003
	25%	BTP ↑ NL	p = .040				

The pairwise comparisons broken down to show where significant differences occurred for each variable during walking trials. Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

Table 3. Mean (SD) of kinematic variables during static trials pre- and post-walk.

Head Angle ^{a,b,c}				
	15%		25%	
	Pre-Walk	Post-Walk	Pre-Walk	Post-Walk
NL	-30.89 (8.37)	-29.48 (8.85)	-30.89 (8.37)	-29.48 (8.85)
BTP	-24.20 (9.27)	-21.60 (8.00)	-21.79 (9.10)	-20.20 (8.93)
BP	-19.62 (10.14)	-17.93 (9.47)	-16.40 (9.49)	-14.60 (9.43)

Trunk Angle ^{a,b}				
	15%		25%	
	Pre-Walk	Post-Walk	Pre-Walk	Post-Walk
NL	7.43 (2.63)	7.96 (2.64)	7.43 (2.63)	7.96 (2.64)
BTP	3.69 (2.86)	3.26 (2.84)	2.20 (2.69)	2.07 (2.74)
BP	-2.14 (4.10)	-0.98 (3.04)	-5.90 (4.77)	-4.86 (3.09)

Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

a: $p < .05$ collapsed across backpacks

b: $p < .05$ collapsed across load

c: $p < .05$ collapsed across time

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Appendix

Table 1. Mean (SD) of kinetic and kinematic variables during walking trials.

Kinetic Variables

	No Load	BTP 15%	BTP 25%	BP 15%	BP 25%
Impact Peak (VGRF)^{a,b}	1.20 (.09)	1.37 (.08)	1.49 (.08)	1.35 (.08)	1.47 (.08)
Loading Rate	2.64 (.63)	2.58 (.54)	2.57 (.55)	2.55 (.66)	2.45 (.60)
Sag Knee Moment^{a,b}	1.01 (.24)	1.12 (.29)	1.29 (.29)	1.20 (.30)	1.44 (.35)
Frontal Knee Moment^b	0.67 (.16)	0.77 (.20)	0.79 (.22)	0.74 (.20)	0.82 (.20)
Sag Hip Moment^a	1.04 (.21)	1.38 (.88)	1.57 (.94)	1.02 (.53)	1.12 (.65)
Frontal Hip Moment^a	1.18 (.23)	1.92 (1.20)	1.71 (.94)	1.26 (.25)	1.52 (.65)

Kinematic Variables

	No Load	BTP 15%	BTP 25%	BP 15%	BP 25%
Head Angle^{a,b}	-19.12 (10.38)	-12.66 (9.58)	-11.46 (9.79)	-9.02 (9.24)	-6.09 (9.96)
Trunk Angle^{a,b}	1.75 (3.87)	-2.77 (4.29)	-5.12 (3.68)	-7.94 (4.48)	-12.14 (4.80)
Impact Knee Angle^{a,b}	0.50 (3.46)	1.15 (3.46)	1.31 (3.77)	0.99 (3.65)	3.44 (4.35)
Peak Hip Angle^{a,b}	36.54 (4.88)	38.58 (4.95)	39.48 (5.01)	39.81 (5.44)	42.74 (5.92)

Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

a: $p < .05$ collapsed across backpacks

b: $p < .05$ collapsed across load

Table 2. Post-Hoc Comparisons for 15% and 25% Significant Main Effects.

Kinetics	Load	Post-Hoc Differences	Post-Hoc Significance	Kinematics	Load	Post-Hoc Differences	Post-Hoc Significance
Impact Peak (VGFRF)	15 & 25%	BTP ↑ NL BP ↑ NL	p < .001 p < .001	Head Angle	15%	NL ↑ BTP NL ↑ BP BTP ↑ BP	p < .001 p < .001 p = .001
Loading Rate	25%	NL ↑ BP	p = .016		25%	NL ↑ BTP NL ↑ BP BTP ↑ BP	p < .001 p < .001 p < .001
Sag Knee Moment	15%	BTP ↑ NL BP ↑ NL	p = .027 p < .001				
	25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p = .001	Trunk Angle	15 & 25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p < .001
Frontal Knee Moment	15 & 25%	BTP ↑ NL BP ↑ NL	p < .001 p < .001	Impact Knee Angle	25%	BP ↑ NL BP ↑ BTP	p = .001 p = .001
Sag Hip Moment	25%	BTP ↑ NL	p = .036	Peak Hip Angle	15%	BTP ↑ NL BP ↑ NL	p = .001 p < .001
Frontal Hip Moment	15%	BTP ↑ NL BTP ↑ BP	p = .024 p = .044		25%	BTP ↑ NL BP ↑ NL BP ↑ BTP	p < .001 p < .001 p = .003
	25%	BTP ↑ NL	p = .040				

The pairwise comparisons broken down to show where significant differences occurred for each variable during walking trials. Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

Table 3. Mean (SD) of kinematic variables during static trials pre- and post-walk.

Head Angle ^{a,b,c}				
	15%		25%	
	Pre-Walk	Post-Walk	Pre-Walk	Post-Walk
NL	-30.89 (8.37)	-29.48 (8.85)	-30.89 (8.37)	-29.48 (8.85)
BTP	-24.20 (9.27)	-21.60 (8.00)	-21.79 (9.10)	-20.20 (8.93)
BP	-19.62 (10.14)	-17.93 (9.47)	-16.40 (9.49)	-14.60 (9.43)

Trunk Angle ^{a,b}				
	15%		25%	
	Pre-Walk	Post-Walk	Pre-Walk	Post-Walk
NL	7.43 (2.63)	7.96 (2.64)	7.43 (2.63)	7.96 (2.64)
BTP	3.69 (2.86)	3.26 (2.84)	2.20 (2.69)	2.07 (2.74)
BP	-2.14 (4.10)	-0.98 (3.04)	-5.90 (4.77)	-4.86 (3.09)

Abbreviations: No Load (NL), BackTpack (BTP), Backpack (BP)

a: $p < .05$ collapsed across backpacks

b: $p < .05$ collapsed across load

c: $p < .05$ collapsed across time

Informed Consent

“Load Distribution and Postural Changes When Wearing a Traditional Backpack Versus the BackTpack”

Who is conducting the study?

This is a scientific research study conducted by Kimi Dahl and Dr. Clark Dickin in the biomechanics program at Ball State University.

What is the purpose of this study?

The purpose of the study is to identify load distribution and postural changes between a traditional backpack and a nontraditional backpack.

What criteria must be met for me to participate in this study?

- Males and females age 18-30 years
- You have a history of carrying a traditional backpack on a regular basis (3+ days/week)
- You have not used a BackTpack before
- You are free from lower extremity and back injury and any other musculoskeletal or neurological condition which would inhibit your ability to carry a backpack at 15% and 25% of your body weight

Where is the study going to take place and how long will it last?

The study will take place in the Ball State University Biomechanics Laboratory, HP 311. Your participation in the study will consist of one visit to the Biomechanics Laboratory. This visit will last approximately 1.5 to 2 hours.

What will I be asked to do?

You will be informed of the protocol and asked to read and sign the Informed Consent document. You will also be asked to fill out a health questionnaire reporting things such as any injuries, a brief medical history, and your backpack history.

You will then be asked to change into compression clothing, and you will have reflective markers attached to your skin at specific joint locations. Following calibration trials, data will be collected of you standing still and walking for 6 minutes on a treadmill without any backpack on. You will then be asked to do the same movements (standing still and walking) with one of the backpacks loaded at 15% and 25% of your body weight. Lastly, you will do the same movements (standing still and walking) but with the second backpack loaded at 15% and 25% of your body weight.

What are the possible risks and discomforts?

You may experience minor muscular fatigue and discomfort due to having to carry 15% and 25% of your body weight in the backpacks. The traditional backpack places the weight on your back, and the nontraditional backpack places the load around your hips. This study also involves walking, which is of minimal risk since it is a movement you perform daily. Research staff will be available on the side to

provide necessary support if you become injured. These risks are remote and all reasonable precautions will be taken to prevent such injury. If any injury were to occur, the Ball State University emergency response guidelines will be followed. You can view these guidelines on the following website (<http://cms.bsu.edu/About/AdministrativeOffices/EmergencyPrepared/Guidelines/WorkplaceSituations/MedEmergencies.aspx>).

Do I have to take part in this study and will I benefit from it?

Your participation in this study is completely voluntary. You are free to stop the study at any time for any reason without consequences or judgment from any member of the research team. Your participation in this research study may help to advance the research of backpack weight distribution and nontraditional backpack styles. Please feel free to ask questions to clarify any part of this form before signing it.

Who will see the information that I give?

The data collected during this study will remain confidential. Each participant will be assigned a subject number at the beginning of the study. You will not be identified in any way in publication or presentation of this research. Only members of the research team will have access to the data. All written records will be stored in a locked file cabinet in a locked room. All 3-D motion capture data will be stored on a password protected computer. Both written data and data stored on computers will be deleted 3 years from the completion of the project. By signing this form, however, you allow the research investigators to make your records available to the Office of Research Integrity at Ball State University and regulatory agencies as required by law.

What happens if I get hurt or sick during the study?

It is understood that in the unlikely event of an injury or illness of any kind as a result of your participation in this research project that Ball State University, its agents and employees will assume whatever responsibility is required by law. In the event that you should require it, emergency care will be provided to you at your expense. If any injury or illness occurs in the course of your participation in this research project, please notify Kimi Dahl, Dr. Clark Dickin, or the Biomechanics Laboratory at (765) 285-5178.

What if I have questions?

If you have any questions concerning your involvement in this study, you may contact the Biomechanics Laboratory at (765) 283-5178 at any time.

Consent

I, _____, agree to participate in this study, "Load Distribution and Postural Changes When Wearing a Traditional Backpack Versus the BackTpack." I have had the study explained to me, and my questions have been answered to my satisfaction. I have read the description and give my consent to participate. I understand that I can withdraw my consent at any time during the study if I feel uncomfortable. I understand that I will receive a copy of this informed consent form for my own reference.

I understand that my participation in this study depends on my age and activity level and that I may not be selected if I do not meet the necessary criteria. To the best of my knowledge, I meet the inclusion criteria for participation in this study.

Participant Signature

Date

Participant Name (Printed)

Signature of Investigator

Principle Investigators

Kimi Dahl
Biomechanics Laboratory
Ball State University
Muncie, IN 47306
Telephone: (765) 285-5178
Email: kdahl@bsu.edu

Dr. Clark Dickin
Biomechanics Laboratory
Ball State University
Muncie, IN 47306
Telephone: (765)-285-5178
Email: dcdickin@bsu.edu

For questions about your rights as a research subject, please contact:

Office of Research Integrity
Ball State University
Muncie, IN 47306
(765) 285-5070
E-mail: irb@bsu.edu

Health/Activity Information (YA)

Biomechanics Laboratory - Ball State University

Subject ID _____
 Gender: Male ___ Female ___
 Age: _____ Height: _____ Weight: _____
 Emergency contact: _____ Phone # _____
 Name of your physician: _____ Phone # _____

2. Have you ever been diagnosed as having any of the following conditions?

Yes (X) Year of onset (Approximate)

Heart attack _____	Other neurological conditions _____
Transient ischemic attack _____	_____
Angina (chest pain) _____	Osteoporosis _____
High blood pressure _____	Rheumatoid arthritis _____
Stroke _____	Other arthritic conditions _____
Peripheral vascular disease _____	Visual/depth perception problems _____
_____	_____
Diabetes _____	Inner/Recurrent ear infections _____
Neuropathies _____	Cerebellar problems (ataxia) _____
Respiratory disease _____	Other movement disorders _____
Parkinson's disease _____	Chemical dependency _____
Multiple sclerosis _____	Depression _____
Polio/Post polio syndrome _____	Cognitive condition _____
Epilepsy/seizures _____	

3. Have you ever been diagnosed as having any of the following conditions?

Yes (X) Describe what kind.

Cancer _____
 Joint replacement _____
 Uncorrected visual problems _____
 Other health problem? _____

4. Do you currently suffer any of the following symptoms in your legs or feet?

Yes (X)

Numbness ___ Tingling ___ Arthritis ___ Swelling ___

5. Do you currently have any medical conditions for which you see a physician regularly? Y/N

If YES, please describe the condition(s) _____

6. List all medications that you currently take (including 'over-the-counter' medications)

Type of Medication	For what condition
_____	_____
_____	_____
_____	_____
_____	_____

7. Have you required emergency medical care or hospitalization in the last three years? Y/N

If YES, please list when this occurred and briefly explain why.

8. Have you ever had any condition or suffered any injury that has affected your balance or ability to walk without assistance? Y/N

If YES, please list when this occurred and briefly explain condition or injury.

9. Do you require eyeglasses? YES or NO**10. Do you require hearing aids? YES or NO****11. How would you describe your health?**

Excellent ____ Very good ____ Good ____ Fair ____ Poor ____

12. Approximately how long has it been since your last meal? _____**13. If you smoke, how long has it been since your last cigarette/cigar/pipe/chewing tobacco?**

14. Approximately how long has it been since you consumed any caffeine?

(e.g., cola drinks, coffee, chocolate milk or hot chocolate, energy drinks) _____

Backpack History**1. How many days per week do you use a backpack?**

One ____ Two ____ Three ____ Four ____ Five ____ Six ____ Seven ____

2. How many years have you used a backpack?

____ Less than one year

____ 1-3 years

____ 4-7 years

____ More than 7 years

3. Do you experience pain from wearing your backpack? If yes, please briefly explain.

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